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# **Testbed Roundup: Unmanned Aircraft Systems (UAS)**

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NOAA Unmanned Aircraft Systems (UAS) Program**

**2 April 2013**



# NOAA UAS Strategic Vision and Goals



- ***Vision***

- UAS will revolutionize NOAA observing strategies by 2015 comparable to the introduction of satellite and radar assets decades earlier

- ***Goals***

- Goal 1: Increase UAS observing capacity
- Goal 2: Develop high science-return UAS missions
  - ***High impact weather monitoring,***
  - ***Polar monitoring***
  - ***Marine monitoring***
- Goal 3: Transition cost-effective, operationally feasible UAS solutions into routine operations





# NOAA UAS Program

## Analysis of Alternatives

## Recommendations



UAS Category	Gross Takeoff Weight (lb)	Operating Altitude (ft)	Range (nm)	Endurance (hrs)	NOAA UAS Program Recommendation
High Altitude Long Endurance (HALE)	> 1320	> 50,000	6,000 – 11,000	24 - 30	Northrop Grumman Global Hawk
Medium Altitude Long Endurance (MALE)	< 1320	18,000 – 50,000	2,000 – 6,000	24 - 30	General Atomics Predator (Ikhana)
Low Altitude Long Endurance (LALE)	21 - 1320	1,200 – 18,000	200 – 2,000	20 - 24	In Situ-Boeing Scan Eagle
Low Altitude Short Endurance (LASE)	0 - 20	< 1,200	10 - 200	2	AeroVironment Puma



# Advancing Technology Readiness of Global Hawk UAS



- **NASA / NOAA Global Hawk Pacific (2010)**
  - First Global Hawk science mission
  - Flights spanned 12 to 85 deg N Latitudes
  - NOAA Corp Officer becomes first certified NASA Global Hawk pilot
- **NASA Genesis and Rapid Intensification Processes (2010)**
  - First Global Hawk flights over tropical cyclones
  - Real-time data delivery
- **NOAA Winter Storm Pacific and Atmospheric Rivers (2011)**
  - First operational dropsonde deployment, 177 sondes total
  - First dropsonde in the Arctic since 1950s
- **NASA Hurricane Severe Storm Sentinel (2012 – 2013)**
  - Three-year experiment deploying 2 Global Hawks
  - 2011 test flight comparison of G-IV and Global Hawk dropsondes shows very good agreement
  - First East Coast deployment of Global Hawk
  - Three NOAA Corps certified pilots and maintenance crew
  - Dropsonde data delivered in real-time to National Hurricane Center





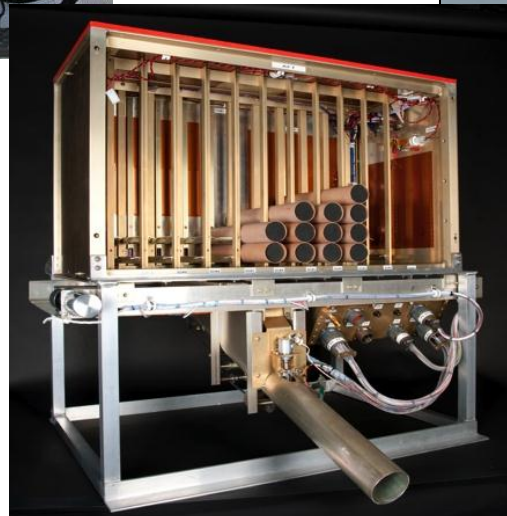
# NOAA Advanced Vertical Atmospheric Profiling System (AVAPS) Developed by National Center for Atmospheric Research



Dropsonde System Electronics



Dropsonde System Launch Tube



Dropsonde Launch Assembly



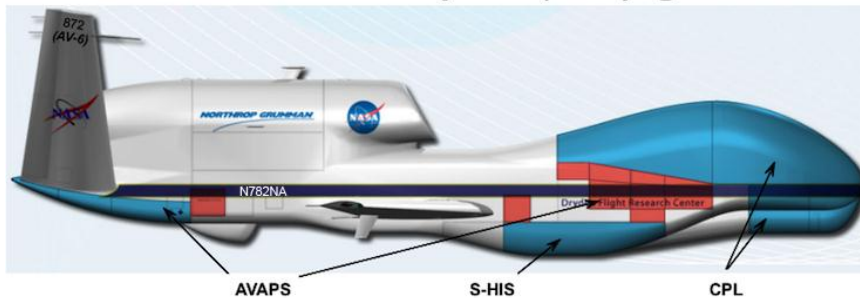




# NASA Hurricane Severe Storm Sentinel (HS3) Experiment



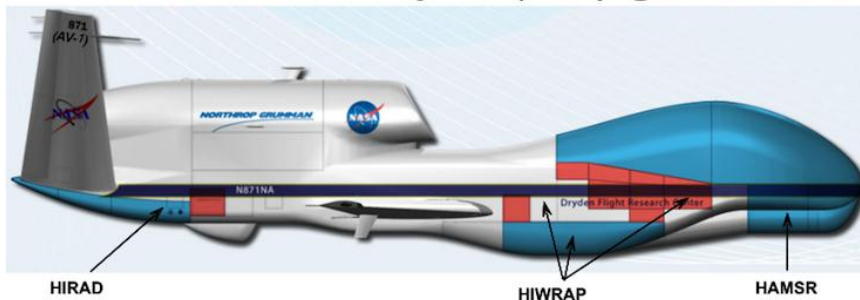
**HS3 Environmental Payload (AV-6) @ WFF '12**



## Environment Observations

- Profiles of temperature, humidity, wind, and pressure (AVAPS)
- Cloud top height (CPL)
- Cloud top temperature and profiles of temperature and humidity (S-HIS)

**HS3 Over-Storm Payload (AV-1) @ WFF '12**



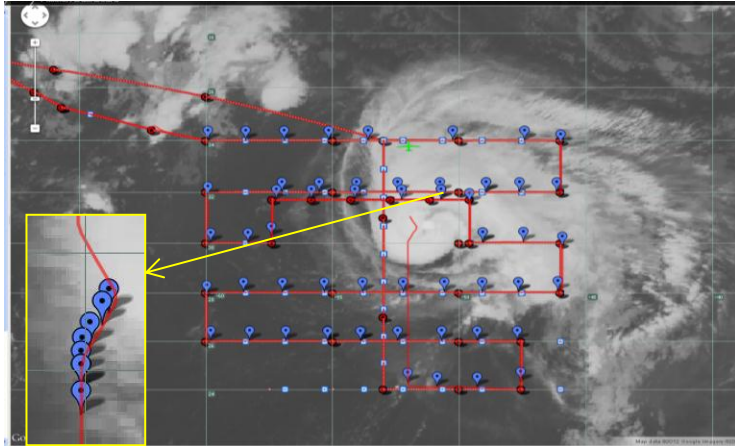
## Over-storm Observations

- Doppler velocity, horizontal winds, and ocean surface winds (HIWRAP)
- Profiles of temperature and humidity and total precipitable water (HAMSR)
- Ocean surface winds and rain (HIRAD)

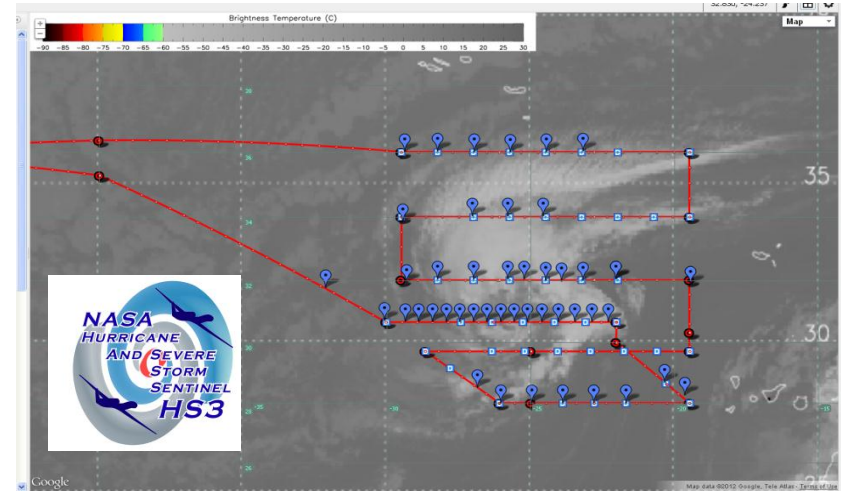




# Advanced Vertical Atmospheric Profiling System (AVAPS) HS3 2012 Sample Results



**Nadine flight and rapid launch sequence  
14 September 2012**



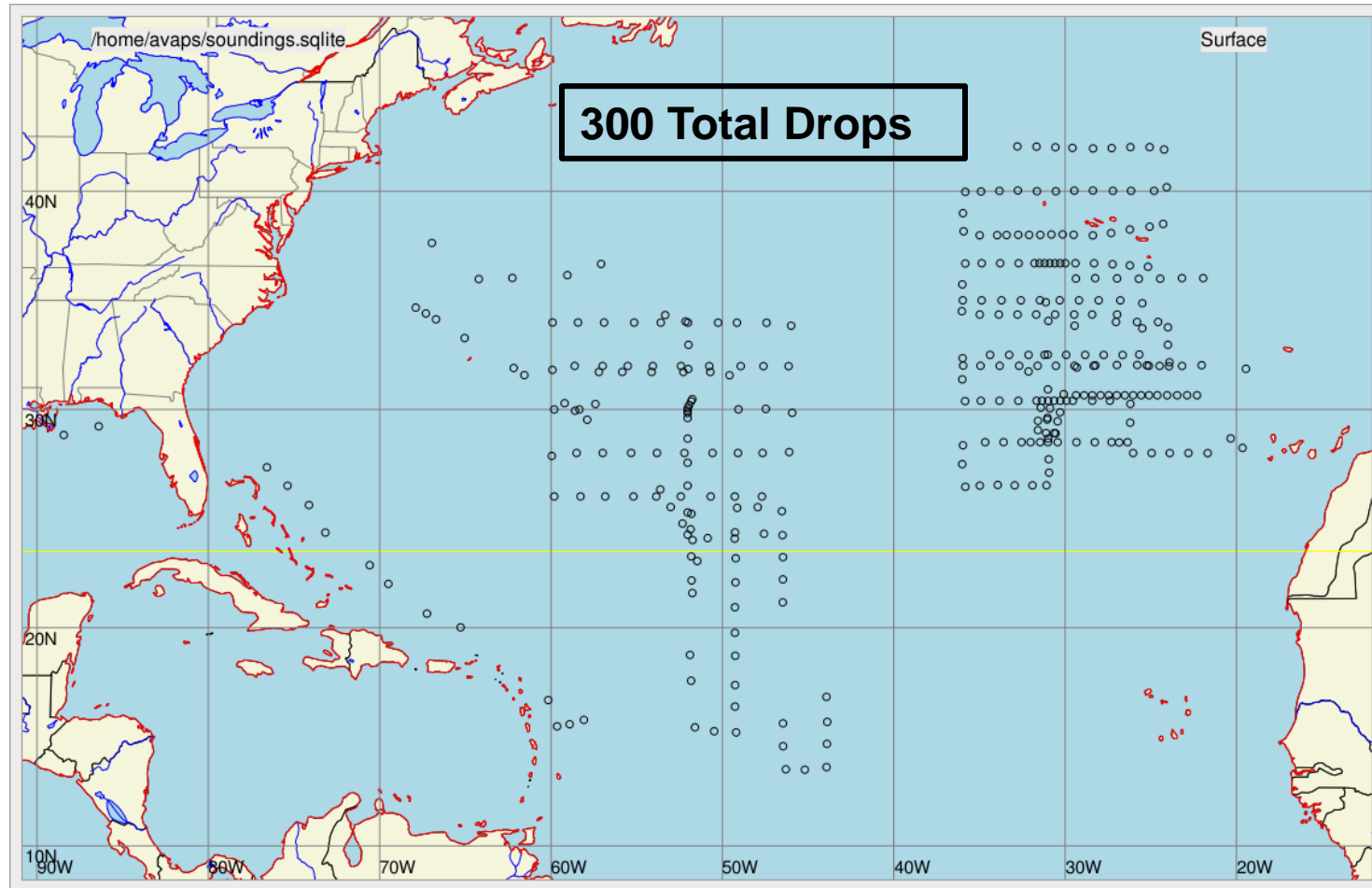
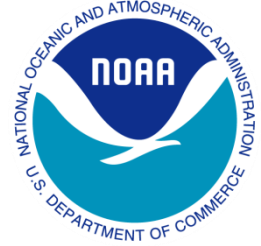
**Nadine flight 22-23 September 2012**

***TROPICAL STORM NADINE  
DISCUSSION NUMBER 44  
NWS NATIONAL  
HURRICANE CENTER  
1100 AM AST SUN SEP 23  
2012***

BASED ON THE IMPROVED SATELLITE APPEARANCE AND TROPICAL CLASSIFICATIONS OF 2.5 AND 3.0 FROM SAB AND TAFB... NADINE IS CLASSIFIED AS A TROPICAL STORM ONCE AGAIN. DROPSONDE **DATA FROM AN ONGOING NASA GLOBAL HAWK MISSION SUGGESTS THAT THE MAXIMUM WINDS ARE NEAR 50 KT. A DROPWINDSONDE NEAR THE CENTER AROUND 1030 UTC MEASURED A PRESSURE OF 989.9 MB WITH STRONG WINDS...SO THE ESTIMATED MINIMUM CENTRAL PRESSURE IS 986 MB.**



# 2012 Global Hawk Dropsonde Coverage During NASA HS3 Experiment

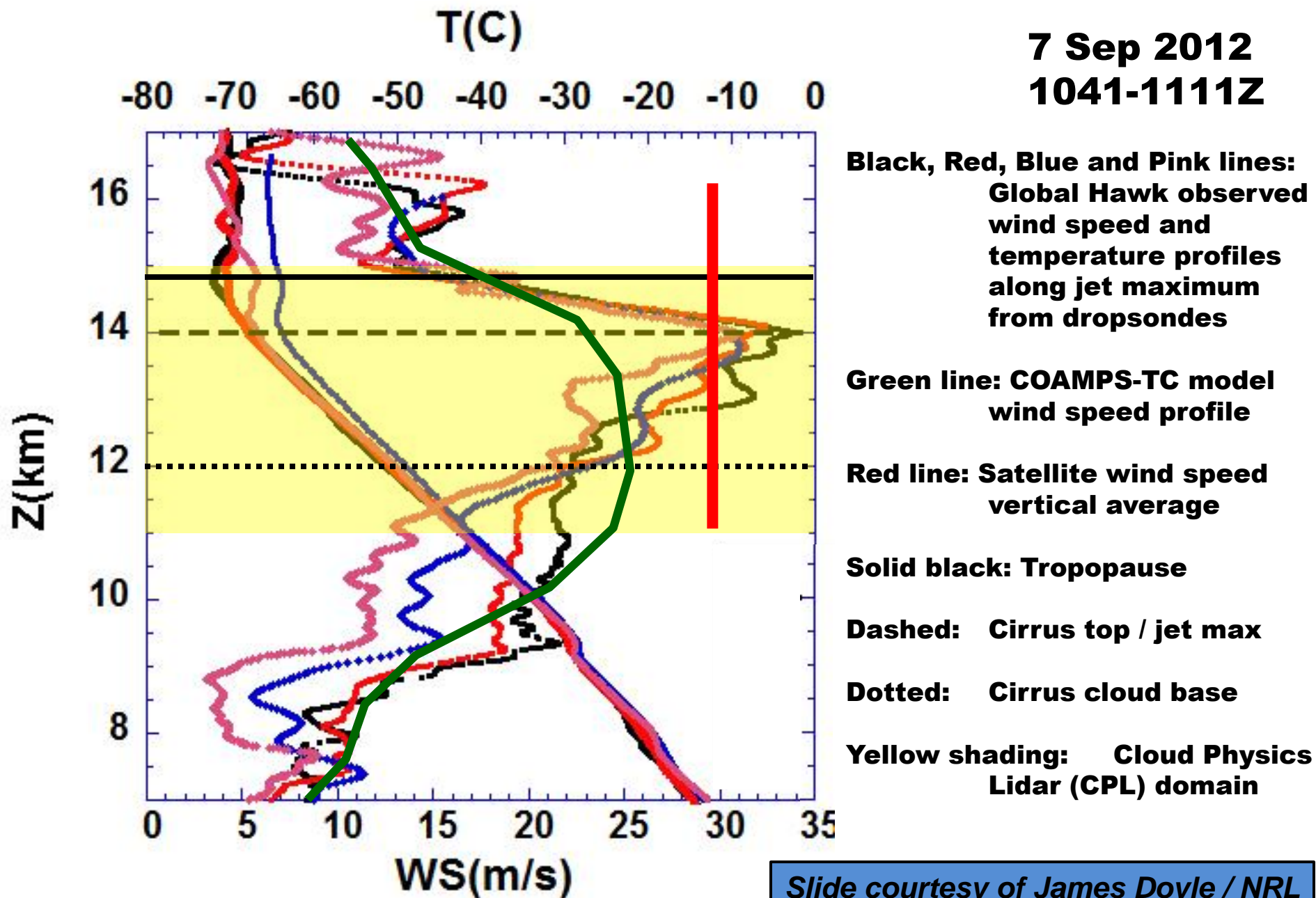




# HS3 Observations of Leslie's Outflow

7 Sep 2012

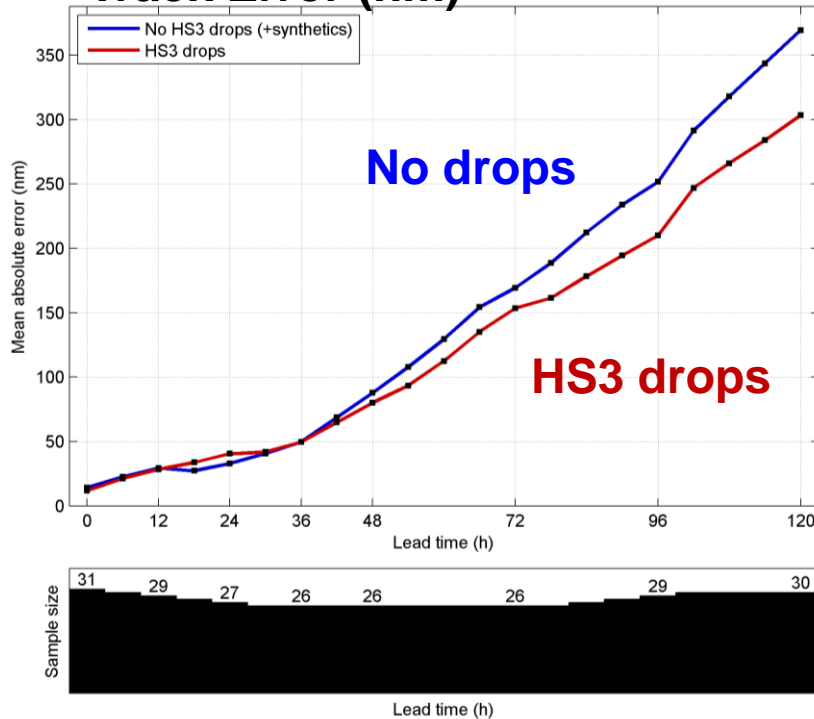
1041-1111Z



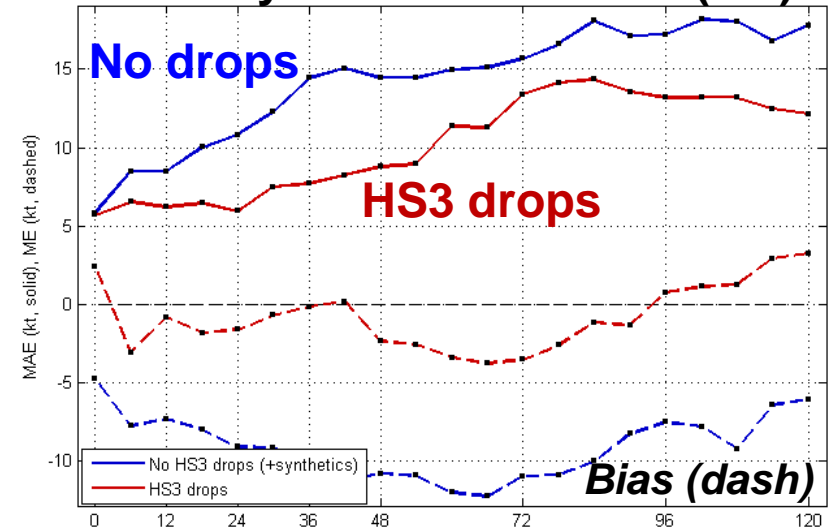
Slide courtesy of James Doyle / NRL

# Impact of HS3 Dropsondes for Navy COAMPS-TC Hurricane Nadine Predictions

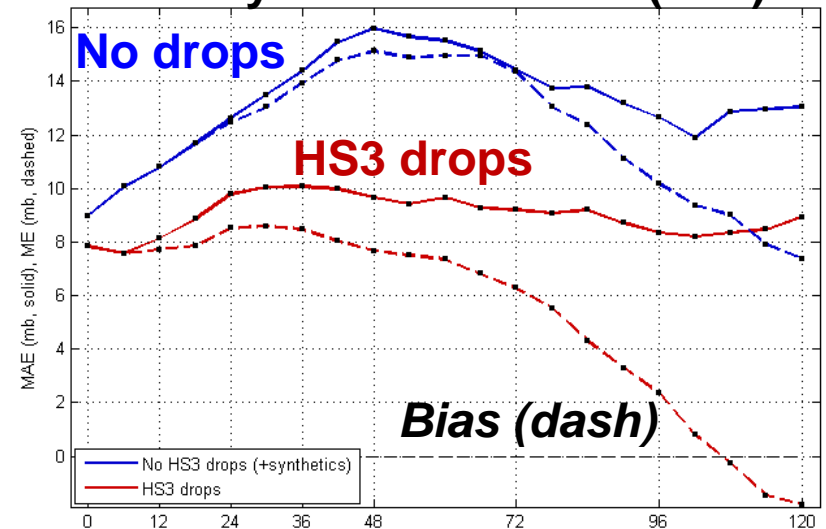
## Track Error (nm)



## Intensity: Max. Wind Error (kts)



## Intensity: Min. SLP Error (hPa)



- Dropsonde impact experiments performed for 19-28 Sep. (3 flights)

- Red: with HS3 drops

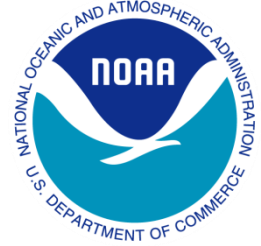
- Blue: No drops with synthetics

- COAMPS-TC Intensity and Track skill are improved greatly through assimilation of HS3 Drops.

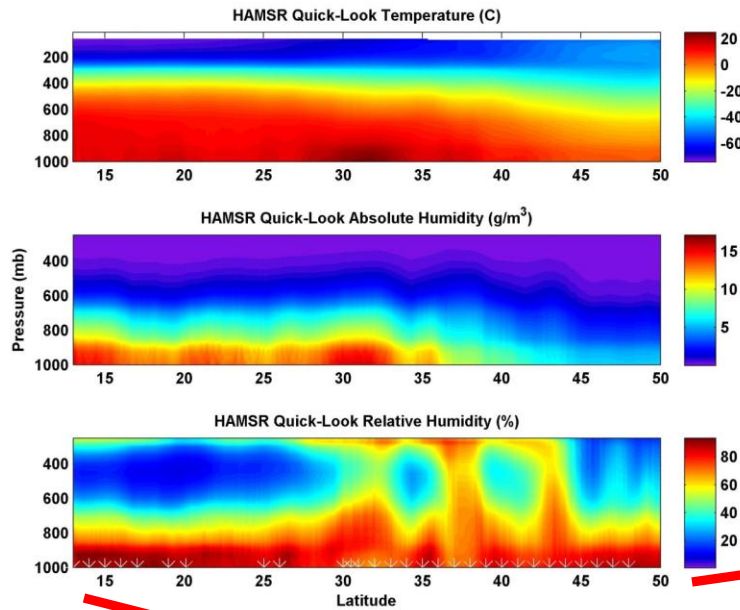
Slide courtesy of James Doyle / NRL



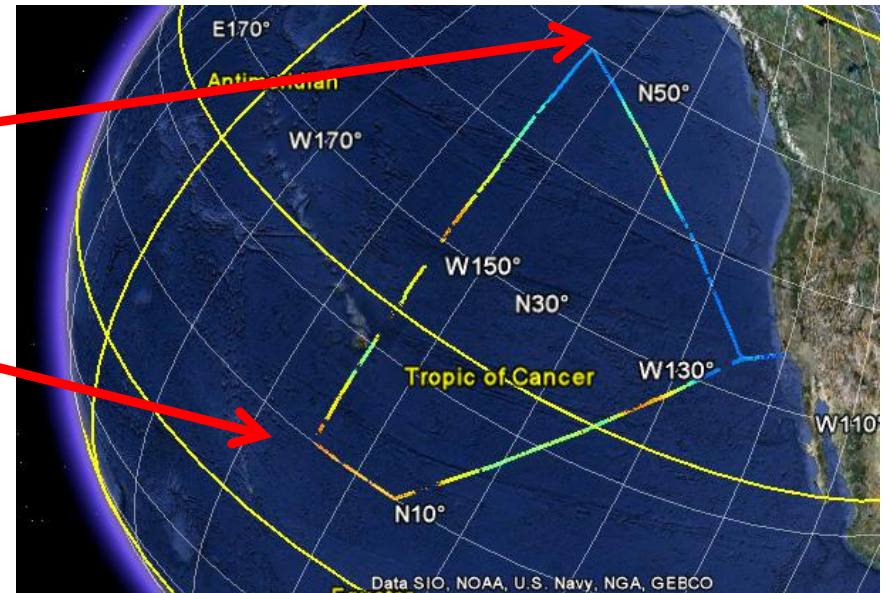
# High Altitude MIMC Sounding Radiometer (HAMSR)



- Scanning passive microwave radiometer built by JPL
- 3-D profiles of temperature, water vapor and cloud liquid water
- Sampling frequencies similar to AMSU and ATMS satellite sensors
- TRL = 9 for research, 7/8 for wx operations



***HAMS Quick-Look profiles shown for N-S leg of Global Hawk flight path during 8 September 2011***







# High Altitude Imaging Wind and Rain Airborne Profiler (HIWRAP)

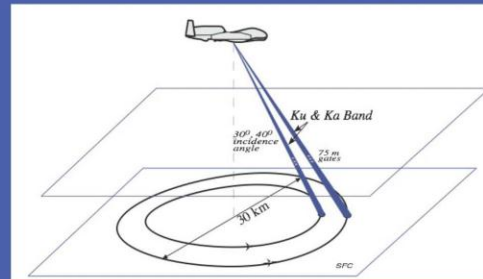


- **Dual-frequency, conically scanning radar/scatterometer sensor built by NASA GFSC**
- **3-D maps of winds and precipitation**
- **Ocean surface winds in clear and light rain**
- **TRL – 9 for research  
7/8 for wx operations**

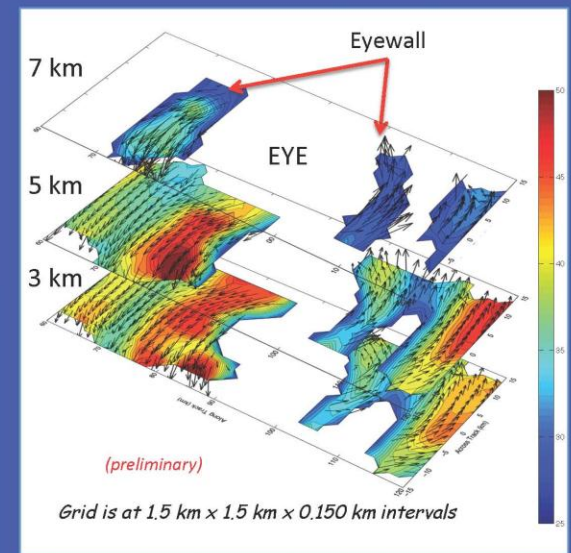
## Retrieved Winds from Hurricane Karl (2010)

- HIWRAP made 20 crossings of Hurricane Karl on September 17, 2010 during GRIP over 14 hours.
- Doppler line of sight wind measurements are continually profiled during the conical scans.
- Horizontal winds are calculated from Doppler winds from multi look angles as the Global Hawk passes across the storm.

HIWRAP Measurement Geometry



Horizontal winds (m/s) and reflectivity (dBZ) derived from one pass across Hurricane Karl's eye/eyewall region



Courtesy S. Guimond/ONAU/GSFC

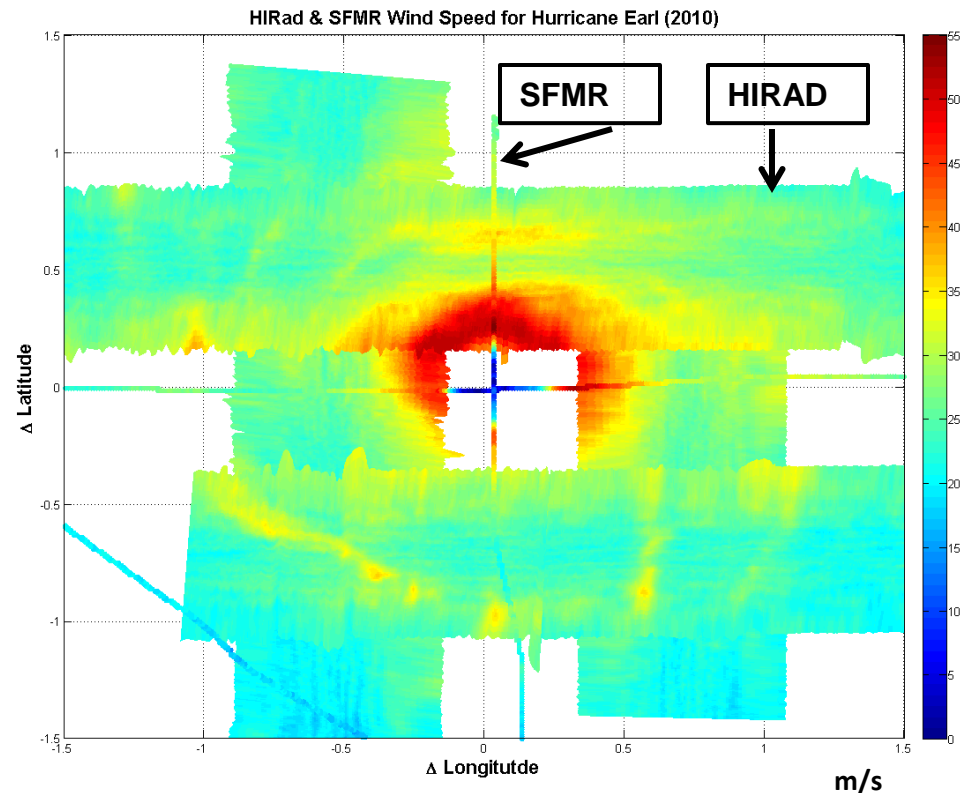


# Hurricane Imaging Radiometer (HIRAD)



- Four frequency synthetic array passive microwave radiometer built by NASA MSFC
- Collaborative partners include NOAA HRD, U of Michigan, and UCF
- Provides ocean surface wind speed and precipitation over 40 km swath
- Frequencies similar to aircraft SFMR used for operational hurricane reconnaissance
- TRL = 7/8 for research,  
= 7 for wx operations

Swath < 65° nadir angle



*Comparison of joint HIRAD and SFMR ocean surface wind observations collected for Hurricane Earl during 2010*





# Thermodynamic Observations for Tropical Cyclones



Obs	NOAA Requirements			HAMSR Capabilities (TRL – 7/8)			AVAPS Dropsonde Capabilities (TRL – 7/8)		
	VR	HR	A	VR	HR	A	VR	HR	A
Temp Profiles	O 500m	O 50 km	O 1 K	1 km	2 km	0.5 K	5 – 15 m	10 km	0.1 K
	R 45 m	R 1 km	R 1 K						
Pressure Profiles	O 9 m	O 10 km	O 1 hPa	N/A	N/A	N/A	5 – 15 m	10 km	0.1 hPa
	R 45 m	R 1 km	R 1 hPa						
Water Vapor Profiles	O 1 km	O 20 km	O 8%	2 km	2 km	15 – 20%	5 – 15 m	10 km	5%
	R 90 m	R 4 km	R 20%						

Obs - Observations   Temp - Temperature   VR -Vertical Resolution   HR -Horizontal Resolution   A- Accuracy  
 O- Operations   R – Research  
 (Assumed 1 hPa = 9 m for Standard Atmosphere)



# Wind Observations for Tropical Cyclones

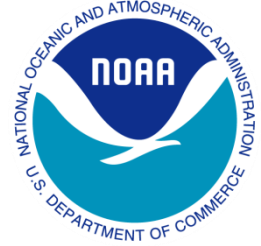


Obs	NOAA Requirements			HIWRAP Capabilities (TRL – 7/8)			HIRAD Capabilities (TRL – 6/7)			AVAPS Dropsonde Capabilities (TRL – 7/8)		
	VR	HR	A	VR	HR	A	VR	HR	A	VR	HR	A
WS Prof	O 500 m	O 50 km	O 1 m/s	60 m	1 km	2 m/s	N/A	N/A	N/A	5- 15 m	10 km	0.5 m/s
	R 100 m	R 50 km	R 1 m/s									
WD Prof	O 500 m	O 50 km	O 10 deg	60 m	1 km	15 deg	N/A	N/A	N/A	5- 15 m	10 km	10 deg
	R 100 m	R 50 km	R 10 deg									
Sfc WS	N/A	O 1 km	O 1m/s	N/A	1 km	2 m/s	N/A	1-2 km	1 - 5 m/s	N/A	10 km	0.5 m/s
	N/A	R 12 km	R 2 m/s									
Sfc WD	N/A	O 2.5km	O 10 deg	N/A	2 km	15 deg	N/A	N/A	N/A	N/A	10 km	10 deg
	N/A	R 12 km	R 20 deg									

Obs - Observations    VR - Vertical Resolution    HR – Horizontal Resolution    A- Accuracy    WS - Wind Speed  
 WD - Wind Direction    Prof - Profiles    Sfc- Surface    O- Operations    R - Research  
 (Assumed 1 hPa = 9 m for Standard Atmosphere)



# Comparison of JPSS and Aircraft Sensors



JPSS Sensor	JPSS Observation	Aircraft Sensor	Aircraft Observation	Aircraft Integration History
ATMS	Remotely sensed atmospheric temperature and moisture profiles	HAMS	Remotely sensed atmospheric temperature and moisture profiles	Global Hawk
		AVAPS	<i>In situ</i> atmospheric temperature and moisture profiles	Global Hawk
CrIS	Remotely sensed atmospheric temperature and moisture profiles	S-HIS	Remotely sensed atmospheric temperature and moisture profiles	Global Hawk
		AVAPS	<i>In situ</i> atmospheric temperature and moisture profiles	Global Hawk
CERES	Solar and Earth radiation	SSFR	Solar and Earth radiation	Global Hawk
OMP	Ozone profiles	ACAM	Ozone profiles and ocean color imagery	Global Hawk
VIIRS	Imagery of clouds, fires, smoke, dust, etc.	eMAS	Imagery of clouds, fires, smoke, dust, etc.	ER-2
		AMS	Imagery of clouds, fires, smoke, dust, etc.	Ikhana

*Acronyms are defined in the Backup Slides*



# AeroVironment Puma





# Environmental Monitoring of National Marine Sanctuaries



## Shoreline Assessments



## Fisheries Law Enforcement



## Wildlife Surveys



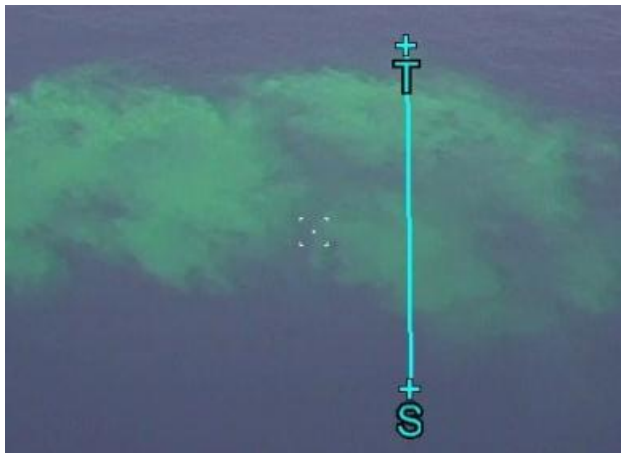




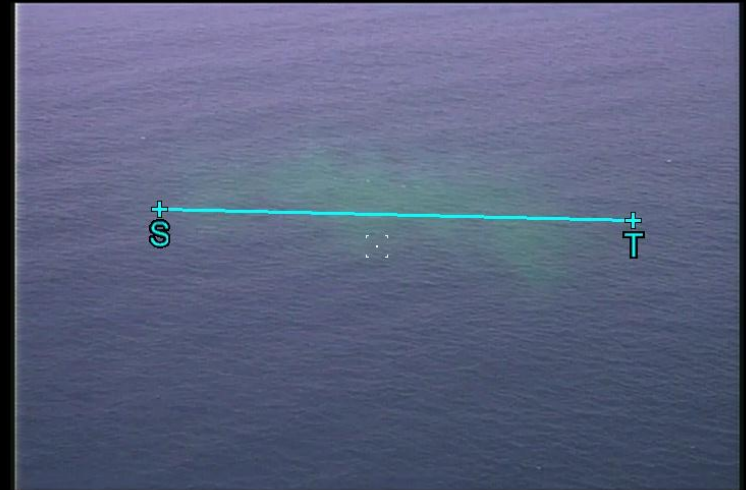
# Oil Spill Simulation



**Coast Guard UAS partnership study of oil spill monitoring in Santa Barbara channel**



Lat/Lon: N 33° 48' 31.53" W 119° 46' 18.60"  
Alt: 351 ft MSL  
Mag: 39°



Gimbal  
FOV Data:  
Slant Rng: 259 m  
CFOV Hdg: 320°  
CFOV Lat/Lon: N 33° 48' 37.61" W 119° 46' 23.82"  
Horiz. FOV: 29.6°  
  
Targeting Data:  
Target S Lat/Lon: N 33° 48' 36.66" W 119° 46' 26.12"  
Target T Lat/Lon: N 33° 48' 39.29" W 119° 46' 23.45"  
ADD 94 m RIGHT 48 m  
Range: 106 m Mag Bearing: 27°



# NWS Forecasting Context



**Pearl River – Pearl River, LA is southernmost NWS flood forecast point**

**Approximately 12 Hour Travel Time to Slidell, LA and 18 Hours to Highway 90/Lake Pontchartrain-Rigolets Area**

**Forecasters make extrapolations for Slidell area and points south based on historical floods. There is no hydraulic model to accurately depict the ebb and flow of water in tidal plain**

**No flood events with historical rainfall and significant surge for late August (same seasonality) since 1999 Walkiah Bluff Construction**

**(\*\*Few data points for Katrina which took out gauging locations)**



# Pearl River Braid, St. Tammany Parish, LA

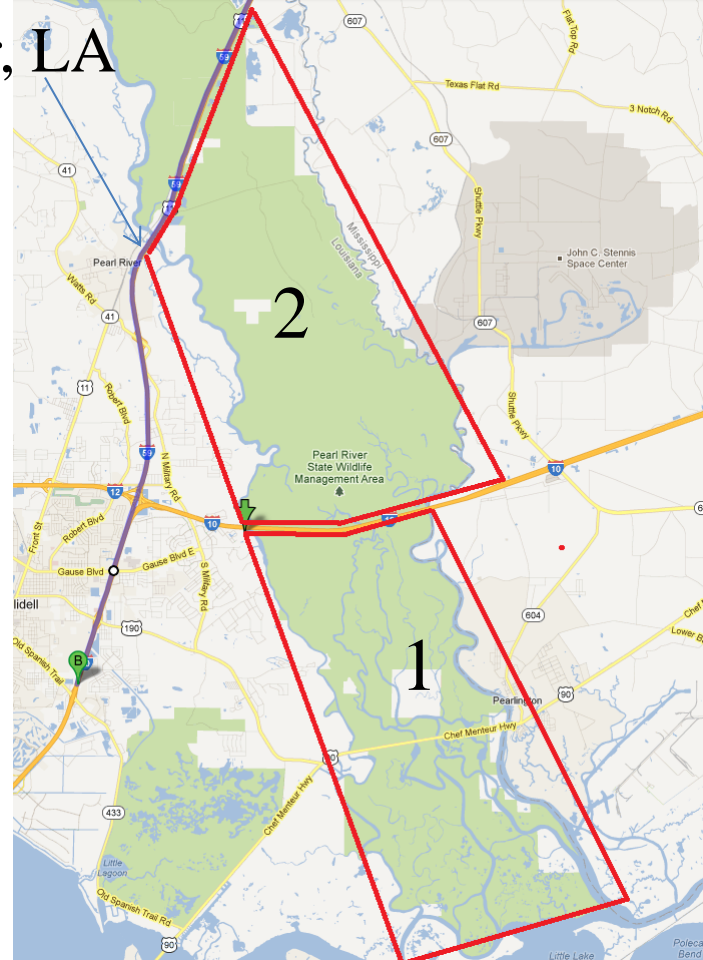


## Pearl River, LA

upper  
sections



lower  
sections







# Contact Information

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**UAS Web Site: <http://uas.noaa.gov/>**



# Backup Slides

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# Definitions of Acronyms

## ***Satellite***

Acronym	Definition
ATMS	Advanced Technology Microwave Sounder
CrIS	Cross-track Infrared Sounder
CERES	Clouds and Earth's Radiant Energy System
OMPS	Ozone Mapping Profiler Suite
VIIRS	Visible / Infrared Radiometer Suite

## ***Aircraft***

Acronym	Definition
ACAM	Airborne Compact Atmospheric Mapper
AMS	Autonomous Modular Sensor
AVAPS	Advanced Vertical Atmospheric Profiling System
eMAS	enhanced MODIS Airborne Simulator
HAMSR	High Altitude MIMC Sounding Radiometer
S-HIS	Clouds and Earth's Radiant Energy System
SSFR	Solar Spectral Flux Radiometer



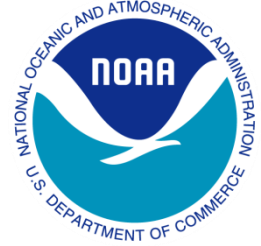
# Metrics for UAS Technology Assessment



Technology Readiness Level	Description
TRL 1	Basic or fundamental research
TRL 2	Technology concept and/or application
TRL 3	Proof-of-concept
TRL 4	Concept validated in laboratory
TRL 5	Concept validated in relevant environment
TRL 6	Prototype demonstration in relevant environment
TRL 7	Prototype demonstration in operational environment
TRL 8	System demonstration in an operational environment
TRL 9	System totally operational



# NASA HS3 Over Storm Products



## Real-Time Products—Over Storm

	Measurements	Horizontal Resolution	Vertical Resolution	Available in RT (yes/no)	Data formats	Method for sharing	Rrestrictions on sharing?
HIWRAP	Reflectivity	1.0 km	0.2 km	TBD			
	Doppler velocity	1.0 km	0.2 km	TBD			
	Horizontal winds	1.0 km	0.5 km	TBD			
	Surface winds	2.0 km	N/A	TBD			
HAMSR	Brightness Temperature	2 km	NA	YES			
	Profiles of temperature	2 km	2 km	YES			
	Profiles of humidity	2 km	2 km	YES			
	dBZ product	2 km	2 km	YES			
	TPW	2 km	NA	YES			
	CAPE, LI, etc.	2 km	NA	TBD			
HIRAD	Excess Brightness Temperature	<3 km	NA	TBD			
	Surface wind speed	<3 km	NA	TBD			



# NASA HS3 Environment Products



## Real-Time Products—Environment

	Measurements	Horizontal Resolution	Vertical Resolution	Available in RT (yes/no)	Data formats	Method for sharing	Restrictions on sharing?
CPL	Attenuated backscatter profiles	1-sec to 1-min depending on KU system	30 m	YES			
	Cloud Top Height		NA	TBD			
SHIS	IR TB spectra	2 km	NA	TBD			
	Cloud Top T	2 km	NA	TBD			
	Preliminary Temperature profiles	2 km	1-3 km	YES			
	Preliminary Humidity profiles	2 km	1-3 km	YES			
TWiLiTE	Doppler velocity	2 km	250 m	YES			
	Horizontal winds	4-8 km	250 m	TBD			
Dropsondes	Profiles of temperature	Varies	5-15 m	YES	ASCII, image(?)		
	Profiles of humidity	Varies	5-15 m	YES	ASCII, image(?)		
	Profiles of wind	Varies	5-15 m	YES	ASCII, image(?)		
	Profiles of pressure	Varies	5-15 m	YES	ASCII, image(?)		